Studies on Structural, Morphological and Optical Properties of Carbon Quantum Dots and its Composite for Energy Storage Applications

Synopsis submitting to fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

P H Y S I C S

Submitted By

Sapna Sharanappa

Ph.D. student

Under the supervision of

Dr. Devendrappa H

Professor

Department of Studies in Physics,
Mangalore University
Mangalagangothri, Karnataka - 574 199.

May 2025

Ph.D. Registration Details

Name of the Candidate	Sapna Sharanappa Ph.D. student Department of Physics, Mangalore University, Mangalagangotri-574199
Name of the Research Guide	Dr. Devendrappa H Professor Department of Physics, Mangalore University, Mangalagangotri-574199
Address of the Work Place	Department of Physics, Mangalore University, Mangalagangotri-574199
Title of the Research work	Studies on Structural, Morphological and Optical Properties of Carbon Quantum Dots and its Composite for Energy Storage Applications
Date of Registration	29-10-2021
Registration Number	MU/EXB/Ph.D./CR.68/Phy. /2022-23/E.25 Dated: 08.06.2023.

1. Introduction

The increasing demands of the population, the rapid depletion of non-renewable energy sources, and growing environmental concerns are becoming more acute, highlighting the urgent need for alternative and sustainable energy solutions. This shift helps address both rising energy demands and environmental issues. Energy storage devices are playing a critical role in integrating renewable energy sources [1], Supercapacitors, a type of electrochemical capacitor, offer an exciting new way to store energy [2]. Supercapacitors are a promising alternative for next-generation energy storage devices due to their high specific power, rapid charge/discharge capabilities, low cost, long lifespan and environmental stability [3]. Generally, supercapacitors are classifying as electric double layer capacitors (EDLC), pseudo capacitors and hybrid super capacitors based on their charging-discharging mechanism. The EDLC stores energy through the accumulation of positive and negative ions at the electrode and electrolyte interface, frequently citing carbon-based materials like carbon nanotubes, activated carbon and graphene as potential electrode candidates so far. In the meantime, the pseudocapacitor stores electricity in a faradaic way using conductive polymers (like polypyrrole, polythiophene, polyaniline, 3, 4-propylenedioxythiophene, etc.) and transition metal oxides (like NiO, V_2O_5, RuO_2, CeO_2, Co_2O_3 , MnO_2, etc.) as an electrode material

[4-5]. The hybrid supercapacitors combine advantages of the above two type of capacitors and exhibit high electrochemical performance. Recently, pseudocapacitors with rapid and reversible redox reactions have attracted attention due to their higher specific capacitance compared to normal EDLCs as a resulting in a growing interest in employing them as supercapacitors. The electrode materials are deciding component of performance of the supercapacitors [6]. Employing two distinct electrodes or two identical electrodes can create a symmetric or asymmetric supercapacitor. Researchers have developed pseudocapacitors on carbon nanomaterials and

conducting polymers using a variety of electrode materials. Recently, extensively use carbon materials (carbon aerogel, carbon quantum dots, activated carbon, carbon nanotubes, graphene, onion-like carbons and carbide-derived carbon) as electrode materials for supercapacitors due to their large specific surface area, plentiful pore structure, chemical stability and superior electrical conductivity. Researchers are currently working to improve the electrochemical characteristics of carbon materials to tackle the unresolved issues in the supercapacitor mechanism [7]. When it comes to materials, the most important consideration of raw materials, affordable methods, large scale product and environmental stability. Despite the development of several carbon compounds with superior electrochemical performance over activated carbon, activated carbon still dominates the market for carbon electrodes for supercapacitors. The continuous optimization of precursors and preparation procedures to low costs will always be a driving factor in carbon material research and development [8]. But recently, zero-dimensional carbon nanomaterials called carbon quantum dots (CQDs) have emerged as a prominent material in supercapacitor applications due to their porosity and large surface area [9]. They are used in many technical applications like photocatalysis, chemical sensing, drug delivery, bio imaging and energy storage due to their small size (<10 nm), superb water solubility, low cost, good photostability, minimum toxicity, excellent conductivity, photon up conversion mechanism, quantum confinement edge effects and charge transfer by electron excitation performance, which makes them outstanding substitutes in various applications [10-11]. Carbon quantum dots have various functional groups on their surface, a large surface area, pores, and an energy gap transition with conjugated π-domains. These properties make them useful for interacting with free radicals and connecting with organic molecules, such as hydrocarbons, metal ions, aliphatic compounds, aromatic compounds, alicyclic compounds, polymers, biomolecules, and fullerenes, facilitating both ion transfer and volume change. They

can also be used as a better conductive agent to improve conductivity and electrochemical performance. The green synthesis of CQDs provides a number of benefits, such as low-cost raw materials, non-toxic, renewable sources, simple experimental techniques and environmental friendliness [12]. According to a literature review, CQDs have been synthesized from natural green precursors such as tulsi leaves, water melon peel, orange juice, onion waste, ginger, soy beans, milk, gas soot, pomelo peel, lantana camera barriers, grass and the pseudostem of the banana plant [13]. Due to the presence of various components, CQDs synthesized with natural green raw materials exhibit variable surface functional groups. These functional groups can enhance the photoluminescence characteristics of CQDs [14]. This property makes CQDs excellent candidates for developing highly efficient energy storage devices, such as batteries and supercapacitors [15].

Nitrogen Doped Carbon quantum dots (NCQDs)

When CQDs are doped with nitrogen (N), sulfur (S), or other elements, their spectral properties and applications can be enhanced. Thus, nitrogen doped carbon quantum dots (NCQDs) can be obtained. The doping of N elements may alter the electron density, structure, and composition of the doped CQDs, leading to an increase in fluorescence intensity [16-17], which can boost CQDs performance and broaden their applications. Recently, numerous studies have reported on N-doped and N/other atom co-doped CQDs.

Tamarind seed husk (TCQDs) and Rose petal derived carbon quantum dots (RCQDs)

The use of cost-neutral precursors and green fabrication routes to prepare fluorescent carbon quantum dots having cost advantages are of great interest, also enhances its wettability as well as electrical conductivity for electrochemical performance Reports on inexpensive, green synthesis of CQDs indicate the use of biomass. Tamarind (Tamarindus indica), a member of the family Leguminosae, is an evergreen tree growing mainly in the Indian subcontinent. The tamarind fruit

contains up to six seeds. The hulls make up 35–45% of the seeds, and the karnel 60–65%. The tamarind seed husk (TSH) is obtained as a byproduct of tamarind seed [18], and sustainable synthesis of TCQDs from tamarind seed husk by a simple hydrothermal method. Globally, there is widespread cultivation of rose flowers, characterized by their sustained rapid growth. During production, and after usage, large quantities of rose petals are discarded as waste. As a result, it is desirable to use rose petals for waste reduction and cost savings [19]. We present a facile, environmentally friendly method for preparing CQDs from rose petals. Natural materials typically contain various heteroatoms, resulting in CQDs with diverse surface groups and unique properties, even without additional passivation or modification [20]. This has prompted significant efforts to synthesize CQDs from various natural biomass and biowaste. The combination of nanoparticles with pure conducting polymer and graphene-based materials reveals, better electrical and optical properties. Nevertheless, the pure conducting polymer and transition metal oxide from relatively low conductivity and weak electrochemical stability, which is incapable of meeting the requirement of high specific capacitance supercapacitors [21]. To overcome these drawbacks and to improve the electrochemical performance of materials, several approaches such as nanostructure or hybridization with carbon quantum dots have been successfully developed. However, polypyrrole (PPy) is the most optimistic conjugate polymer compared to polythiophene and polyaniline; therefore, polypyrrole is extensively investigated and is a significant electrode material for pseudocapacitors owing to its numerous advantages, including high specific capacitance, great storage stability, a low-cost processing method, excellent thermal, chemical stability, environmental stability, good redox properties and ease of preparation [22-23]. The PPy also has a high electrical conductivity because of its π-conjugated system, which makes it easy for

charges to move around. Additionally, the way it is shaped creates channels that resemble mesopores and might be useful for internal continuous charging transfer [24].

In order to address this issue, researchers incorporated CQDs into polypyrrole to enhance the electrochemical performance of the pseudocapacitive materials, structurally modified the electroactive material, are actively participated in the charge transfer processes within the electrode material. Modification of PPy with CQDs lead to their better separation, which in turn allowed them to maintain their high electrical conductivity. Adding CQDs to polypyrrole structures made them much more porous and dispersible, which made the CQDs/PPy composite better at conducting electricity and improve the electrochemical properties.

In the past few years, the graphene oxide (GO) has received extensive interest in energy storage devices due to its superior properties like high electrical conductivity, large specific surface area (2675 m^2g^{-1}) and excellent chemical stability. Unfortunately, the unavoidable restacking of graphene nanosheets causes difficult electrolyte ion diffusion and low capacitance (from EDLC) restricts their practical application [27]. To resolve this challenge, various allotropes of carbon, such as carbon nanotubes, fullerenes and carbon nanofibers [28], have been added to graphene. However, these additives are relatively expensive, limiting the industrial scale-up of the material. But environmentally friendly RCQDs are incorporated into the GO layers via a one-step hydrothermal process (RCQDs/GO). The effect of RCQDs on the electrochemical characteristics of the materials in terms of their physicochemical properties and performance metrics.

Xuan ian et al. fabricated a CQDs/PPy-NW composite electrode that displayed a specific capacitance of 307 Fg^{-1} at 0.5 Ag^{-1} in a two-electrode system as well as excellent cyclic stability of capacity retention of 82.2 % after 5000 cycles [29].

Arul Prasath et al. studied CQD-MnO_2 nanohybrid for supercapacitor application. The binary nanocomposite showed the highest Csp of 189 Fg^{-1} at 2 Ag^{-1}, and it possessed a cyclic stability of 100 % of initial Csp after 2000 cycles [30].

Jingying Li et al. studied the supercapacitor properties of N, P-CQDs/rGO nanocomposite and obtained the highest Csp of 453.7 Fg^{-1} at 1 Ag^{-1} in a two-electrode system. And a high ED of 15.69 $Whkg^{-1}$ at PD of 325 Wkg^{-1} with excellent cyclic stability of capacity retention of 85.5 % after 10000 cycles [31].

Heba M. et al reported the flower-like MoS_2/N-doped carbon dots (CDs) composite nanospheres for supercapacitor applications. The supercapacitor electrodes showed a specific capacitance as high as 149.21 Fg^{-1} at 0.5 Ag^{-1} in a three-electrode system. The SSC showed a maximum ED of 20.1 $Whkg^{-1}$ at PD of 350 Wkg^{-1} and also exhibited 98% Coulombic efficiency after 5000 cycles [32]

Yesheng Wang et al. fabricated a Ti_3C_2Tx MXene electrode that delivers a high Csp of 441.3 Fg^{-1} at 1 Ag^{-1} in a three-electrode system. The asymmetric SC showed a maximum ED of 25.8 $Whkg^{-1}$ at PD of 350 Wkg^{-1} with excellent cyclic stability of capacity retention of 96.2 % after 10,000 cycles [33].

Elumalai Dhandapani et al. studied the carbon quantum dot-reinforced polypyrrole (PPy/CQDs) for supercapacitor applications. The PPy/CQDs composite electrode showed a specific capacitance as high as 290.35 Fg^{-1} Ag^{-1} in a three-electrode system. An all-solid-state asymmetric supercapacitor (ASC) showed excellent cyclic stability, with a capacity retention of 76.8 % after 10,000 cycles [34].

Periyasami Prabakaran et al. studied pure Co_3O_4 nanoparticles and carbon quantum dots (CQDs) anchored cobalt oxide (Co_3O_4/CQD) nanocomposite for supercapacitor applications. The

Co_3O_4/CQD composite electrode exhibits the highest Csp of 193.8 Fg^{-1} at 4 Ag^{-1} in a three-electrode system. The ASC showed a maximum ED of 2.94 $Whkg^{-1}$ at PD of 426 Wkg^{-1} with 81.8 % capacity retention after 5000 cycles [35].

Abid Inayat et al. reported the synthesis of a simple and cost-effective method for obtaining highly conductive carbon quantum dots by hydrothermal oxidation of spent tea leaves. The CQDs showed a Csp of 274.1 Fg^{-1} at 1 Ag^{-1} in a three-electrode system. The fabricated SSC showed a maximum ED of 41.9 $Whkg^{-1}$ at PD of 250 Wkg^{-1} with excellent cyclic stability of capacity retention of 77.4 % after 5000 cycles [36].

According to the literature review, carbon quantum dots composites are promising for energy storage due to their high specific capacitance, energy and power density, rapid charge/discharge capabilities, and long lifespan. The current study aims to construct a solid-state supercapacitor device (SSC) using carbon quantum dots composites, NCQDs/PPy, RCQDs/GO and TCQDs/PPy-NS, while scrutinizing its optical, structural, morphological and electrochemical characteristics. The homogeneous dispersion of carbon quantum dots has been observed on conducting polymer matrix, e and graphene oxide nanostructures, which greatly improved the composite physical property, mechanical strength, cycle stability and dispersibility. The electrochemical properties demonstrate high specific capacitance, excellent cyclic stability and columbic efficiency.

2. Motivation for this work

Carbon quantum dots are raising stars in the nanotechnology which are gains significant research attention due to various factors like comparatively feasible synthesis, excellent biocompatibility, facile preparing methods, tunable optical and chemical stability are deserve them suitable for energy storage applications. Based on these criteria, carbon quantum dots are ideal candidate having unique potential for application in various research applications. In the past decades, carbon

quantum dots get enormous research interest due to their ideal behavior, which is still to be explored. This can open new opportunities for energy materials where traditional nanomaterials fall short. These material prospects and advantages lead to the following tentative aims and objectives.

3. Aims and objective of the present research work

In order to address the research problem, following research objectives were formulated.

1. To investigate the properties of carbon quantum dots composite materials for supercapacitor applications.
2. To synthesize different carbon quantum dot composite by the hydrothermal and in-situ chemical polymerisation method.
    a. Water-soluble nitrogen doped carbon quantum dots-polypyrrole nanocomposite.
    b. Rose petal derived carbon quantum dots incorporated with graphene oxide nanocomposite.
    c. Tamarind seed husk derived carbon quantum dots incorporated with Polypyrrole nanosphere composite.
3. To examine electrochemical properties of synthesized material by using a cyclic voltammetry (CV), Galvanostatic charging-discharging (GCD) and Electrochemical impedance spectroscopy (EIS).
4. To construct all solid-state symmetric supercapacitor (SSC) using electrodes of CQDs composites to examine the energy storage capacity and investigation of parameters such as specific capacitance, cyclic stability, energy density and power density etc.

4. Novelty of the present investigation

The carbon quantum dots are synthesized via the hydrothermal method and examined their structural, morphological, specific surface area, average pore volume and electrochemical performance. The obtained specific capacitance of CQDs is very low; therefore, it is incorporated the CQDs into polypyrrole, graphene oxide and Polypyrrole nanosphere to enhance the electrochemical properties of the composite material. Also synthesized bio mass-derived, i.e., rose petal-derived CQDs and tamarind seed husk derived CQDs using water as a solvent through the hydrothermal method to avoid toxicity and encourage the environmentally friendly synthesis and coded them as NCQDs/PPy, RCQDs/GO and TCQDs/PPy-NS composite. To the best of our knowledge, for the first time we prepared rose petal waste-derived carbon quantum dots using water as solvent without adding any chemicals as supporting agents. The RCQDs are incorporated with GO via a one-step hydrothermal method; the fabricated RCQDs/GO SSD exhibit a high specific capacitance of 795.45 Fg^{-1} at a current density of 1 Ag^{-1}. These findings demonstrate that CQDs composite material is highly recommended as an electrode material for supercapacitor applications. Furthermore, the findings of this study will aid in the design and development of new electrode materials for supercapacitor applications

5. Brief overview of the thesis

The framework of the thesis is divided into six chapters; the first chapter consisting introduction of the carbon quantum dots and composite such as conducting polymers and graphene oxide and their properties as well as relevance of the materials with reported results on energy storage applications. Second chapter deals with the synthesis method and characterization techniques to employ the synthesized carbon quantum dots using chemical, natural banana Peel and composited with conducting polymer and graphene oxide and supercapacitor fabrication process. Third to fifth

chapters are working chapters which provides the result and discussion of observed results. Third chapter includes the synthesis of water-soluble nitrogen doped carbon quantum dots-polypyrrole (NCQDs/PPy) nanocomposites with various loadings of nitrogen doped carbon quantum dots employing by in-situ chemical polymerisation method for high performance supercapacitor application. Fourth chapter contains synthesis of a high-performance electrode material composed of biomass-derived carbon quantum dots and graphene oxide nanocomposite (RCQD/GO) for applications in symmetric supercapacitors. Fifth chapter focuses on synthesis of tamarind seed husk-derived carbon quantum and polypyrrole nanospheres composite (TCQDs/PPy-NS) for supercapacitor applications. The sixth chapter focuses on the summary and scope for the future work, followed by sections namely references and list of research publications.

Chapter 1: Introduction

This chapter explains the broad information about introduction to carbon quantum dots and composite materials such polypyrrole and graphene oxide, selection, classification, properties and their applications in the supercapacitors with their working mechanism. Literature review for related topic, aim and objective of the work described in details.

Chapter 2: Materials and Experimental Methods

This chapter describes the synthesis methods of carbon quantum dots composite their characterization to analyze the morphology, elemental composition, structural modification, optical absorption, electrode fabrication for supercapacitor device and measurement method of electrochemical parameters.

Chapter 3: Investigation of the energy storage performance of water-soluble nitrogen-doped carbon quantum dots and polypyrrole nanocomposite

This chapter reported on water-soluble nitrogen doped carbon quantum dots-polypyrrole nanocomposite (NCQDs/PPy). Water-soluble nitrogen doped carbon quantum dots (NCQDs) were synthesized via a hydrothermal approach, and nitrogen doped carbon quantum dots-polypyrrole nanocomposites were synthesized using in-Situ chemical polymerization method. The morphology of PPy (cauliflower arrangement in PPy, sponge-like PPy spheres in NCQDs/PPy nanocomposite) was controlled by the addition of smart NCQDs at different concentrations during the synthesis process. The electrochemical performance is investigated through a two-electrode system, and the NCQDs/PPy-2 nanocomposite shows a high specific capacitance (C_{sp}) of 750 Fg^{-1} at a current density (CD) of 1 Ag^{-1} with a wide operating potential window from -0.8 V to 0.8 V. In addition, the fabricated symmetrical device shows an energy density (ED) of 43.47 $Whkg^{-1}$ and a high-power density (PD) of 3129.84 Wkg^{-1}. Besides, the NCQDs/PPy-2 show a higher cycle life span with 77.82 % of capacitance retention and 97.04 % of coulombic efficiency even after 8000 charging and discharging cycles. The constructed SSCs are used to light a commercial red LED, which connects serially and effectively flashes for 1 to 2 min with frequent voltage drops. These findings demonstrate that NCQDs/PPy-2 nanocomposite material is highly recommended as an electrode material for supercapacitor applications. Furthermore, the findings of this study will aid in the design and development of new electrode materials for supercapacitor applications based on the NCQDs/PPy nanostructured material.

Chapter 4: Study of enhanced supercapacitor performance of graphene oxide and rose petal-derived carbon quantum dots: A natural resource towards sustainable energy harvesting and storage

In this chapter, natural rose petal derived carbon quantum dots (RCQDs) with graphene oxide nanocomposite (RCQDs/GO) hold great potential as electrode material for supercapacitors. The novel environmentally friendly RCQDs and RCQDs/GO nanocomposite prepared using hydrothermal method. Raman spectra reveal the presence of more than two layers of GO. FESEM images confirms the layered morphology of graphene oxide and RCQDs homogeneously dispersed on the surface of GO. RCQDs are attached to thin GO sheets, possessing layered structure and expressing a strong interaction between RCQDs within the GO sheets. Excellent decoration of RCQDs on GO sheets may be the result of the strong affinity between them, which provides good optical and electrical properties. The maximum specific capacitance attained by a RCQDs/GO -2 is 795.45 Fg^{-1} at a current density (CD) of 1 Ag^{-1} In addition, the fabricated symmetrical device shows an energy density (ED) of 22.28 $Whkg^{-1}$ and a high-power density (PD) of 808.08 Wkg^{-1}. Besides, the RCQDs/GO -2 show a higher cycle life span with 77.82 % of capacitance retention and 97.04 % of coulombic efficiency even after 10000 charging and discharging cycles. In terms of practical applications, we tried to construct a lab made supercapacitor, which attain a specific capacitance of 27.77 Fg^{-1} at a current density (CD) of 0.1 Ag^{-1} In addition, the fabricated supercapacitor shows an energy density (ED) of 3.12 $Whkg^{-1}$ and a high-power density (PD) of 44.9 Wkg^{-1}. The performance of the lab-made supercapacitor falls short compared to the fabricated symmetrical device in terms of energy and power density. Further optimisation may be needed to improve its overall efficiency for practical applications. Overall, the RCQDs/GO-2 composite exhibits promising performance as a supercapacitor electrode material, with excellent specific

capacitance, energy density, power density and cycle life. These results highlight the potential of RCQDs/GO composites for use in high-performance energy storage devices.

Chapter 5: Study of the supercapacitor performance of tamarind seed husk derived carbon quantum dots embedded with Polypyrrole nanosphere composite

This chapter elaborates the synthesis of tamarind seed husk derived carbon quantum dots and polypyrrole nanosphere composite (TCQDs/PPy-NS) by in-Situ chemical polymerization method. Under hydrothermal carbonization conditions, the TCQDs nucleate, develop, and assemble themselves into tiny spheres without the addition of any surface passivating agent and have consistent dispersion with little agglomeration. The small, spherical-like morphology from HRTEM confirms the formation of TCQDs from tamarind seed husks. The developed TCQDs/PPy-NS SSC device exhibits a an excellent Csp, strong adaptability, outstanding reliability, and its durability. The TCQDs/PPy-NS composite exhibits a high Csp of 400 Fg^{-1} at a CD of 2 Ag^{-1} and an ED of 32 $Whkg^{-1}$ at a PD of 1008.19 Wkg^{-1}. excellent electrochemical performance, large specific power density, outstanding specific energy, and great specific power affordability makes the TCQDs/PPy-NS composite stand out as a highly promising option for various energy storage applications. Its potential extends beyond batteries and sensors, opening up possibilities for its use in future technologies and advancements in the field of energy storage.

Chapter 6: Summary and Scope for future work

This chapter summarizes the present results and outline of the future work and opportunity in this field.

6. References

[1] Z. Guo, Y. Zhao, J. Mu, S. Li, F. Li, Wang, M. Zhang, In situ synthesis of integrated dodecahedron NiO/NiCo2O4 coupled with N-doped porous hollow carbon capsule for high-performance supercapacitors, Ceramics International, 49 (2023) 19652-19663.

[2] J. Mu, Y. Zhao, Z. Guo, Z. Zhang, H. Che, Y. Wang, L. Wang, Rational design of new, efficient, and suitable nickel phthalocyanine reinforced MXene electrodes for supercapacitors, Journal of Energy Storage, 61 (2023) 106768.

[3] Y. Zhao, Z. Feng, Z. Guo, J. Mu, H. Che, Z. Zhang, J. Mu, Fe incorporated ternary Layered Double hydroxides with remarkably improved electrochemical performance towards asymmetric supercapacitors, Ceramics International, 48 (2022) 27369-27378.

[4] Z. Guo, Y. Zhao, J. Mu, Z. Zhang, J. Mu, H. Che, M. Zhang, Fabrication of $NiPS_3$ coupled with hollow porous nitrogen-doped carbon capsules for high-performance asymmetric supercapacitor, Journal of Energy Storage, 61 (2023) 106805.

[5] M. Lian, X. Wu, Q. Wang, W. Zhang, Y. Wang, Hydrothermal synthesis of Polypyrrole/MoS2 intercalation composites for supercapacitor electrodes, Ceramics International, 43 (2017) 9877-9883.

[6] S. M. Benoy, M. Pandey, D. Bhattacharjya, B. K. Saikia, Recent trends in supercapacitor-battery hybrid energy storage devices based on carbon materials, Journal of Energy Storage, 52 (2022) 104938.

[7] N. Choudhary, C. Li, J. Moore, N. Nagaiah, L. Zhai, Y. Jung, J. Thomas, Asymmetric supercapacitor electrodes and devices, Advanced Materials, 29 (2017) 1605336.

[8] X. Yang, T. Lv, J. Qiu, High Mass-Loading Biomass-Based Porous Carbon Electrodes for Supercapacitors: Review and Perspectives, Small, (2023) 2300336.

[9] W. Luo, W. Zeng, H. Quan, M. Pan, Y. Wang, D. Chen, Carbon dots decorated NiCo hydroxycarbonate hierarchical nanoarrays on carbon cloth with high areal capacitance as pseudocapacitor electrode, Journal of Alloys and Compounds, 868 (2021) 159048.

[10] N. Tuccitto, L. Fichera, R. Ruffino, V. Cantaro, G. Sfuncia, G. Nicotra, A. Torrisi, Carbon quantum dots as fluorescence nanochemosensors for selective detection of amino acids, ACS Applied Nano Materials, 4 (2021) 6250-6256.

[11] Z. Ji, D. Ma, W. Dai, K. Liu,X. Shen, G. Zhu, A. Yuan, Anchoring nitrogen-doped carbon quantum dots on nickel carbonate hydroxide nanosheets for hybrid supercapacitor applications, Journal of Colloid and Interface Science, 590 (2021) 614-621.

[12] V. Manikandan, N. Y. Lee, Green synthesis of carbon quantum dots and their environmental applications, Environmental Research, 212 (2022) 113283.

[13] L. Cui, X. Ren, M. Sun, H. Liu, L. Xia, Carbon dots: Synthesis, properties and applications, Nanomaterials, 11 (2021) 3419.

[14] M. Wang, Y. Wan, K. Zhang, Q. Fu, L. Wang, J. Zeng, D. Gao, Green synthesis of carbon dots using the flowers of Osmanthus fragrans (Thunb.) Lour. as precursors: Application in Fe 3+ and ascorbic acid determination and cell imaging, Analytical and Bioanalytical Chemistry, 411 (2019) 2715-2727.

[15] Z. Feng, K. H. Adolfsson, Y. Xu, H. Fang, M. Hakkarainen, M. Wu, Carbon dot/polymer nanocomposites: From green synthesis to energy, environmental and biomedical applications, Sustainable Materials and Technologies, 29 (2021) e00304.

[16] Y. Sun, C. Shen, J. Wang, Y. Lu, Facile synthesis of biocompatible N, S-doped carbon dots for cell imaging and ion detecting, RSC Advances, 5 (2015) 16368-16375.

[17] W. Lu, X. Gong, M. Nan, Y. Liu, S. Shuang, C. Dong, Comparative study for N and S doped carbon dots: synthesis, characterization and applications for Fe3+ probe and cellular imaging, Analytica chimica acta, 898 (2015) 116-127.

[18] P. Sinchaiyakit, Y. Ezure, S. Sriprang, S. Pongbangpho, N. Povichit, M. Suttajit, Tannins of tamarind seed husk: preparation, structural characterization, and antioxidant activities, Natural product communications, 6 (2011) 1934578X1100600619.

[19] Y. Feng, D. Zhong, H. Miao, X. Yang, Carbon dots derived from rose flowers for tetracycline sensing, Talanta, 140 (2015) 128-133.

[20] A. M. Alex, M. D. Kiran, G. Hari, A. Krishnan, J. S. Jayan, A. Saritha, Carbon dots: a green synthesis from Lawsonia inermis leaves, Materials Today: Proceedings, 26 (2020) 716-719.

[21] Y. Minglei, Y. Yadong, W. Jiqiu, L. Lu, K. Menglai, Z. Guanggao, H. Zhongbing, Construction of a hierarchical NiCo2S4@ PPy core–shell heterostructure nanotube array on Ni foam for a high-performance asymmetric supercapacitor, ACS applied materials & interfaces, 8 (2016) 24525-24535.

[22] H. Zhou, H. J. Zhai, X. Zhi, Enhanced electrochemical performances of polypyrrole/carboxyl graphene/carbon nanotubes ternary composite for supercapacitors, Electrochimica Acta, 290 (2018) 1-11.

[23] X. Fan, Z. Yang, N. He, Hierarchical nanostructured polypyrrole/graphene composites as supercapacitor electrode, RSC advances, 5(20) (2015) 15096-15102.

[24] T. Wang, Y. Wang, D. Zhang, X. Hu, L. Zhang, C. Zhao, Z. F. Ma, Structural tuning of a flexible and porous polypyrrole film by a template-assisted method for enhanced capacitance for supercapacitor applications, ACS Applied Materials & Interfaces, 13(15) (2021) 17726-17735.

[25] H. M. El Sharkawy, A. S. Dhmees, A. R. Tamman, S. M. El Sabagh, R. M. Aboushahba, N. K. Allam, N-doped carbon quantum dots boost the electrochemical supercapacitive performance and cyclic stability of MoS2, Journal of Energy Storage, 27 (2020) 101078.

[26] M. Toupin, T. Brousse, D. Bélanger, Charge storage mechanism of MnO2 electrode used in aqueous electrochemical capacitor, Chemistry of Materials, 16 (16) (2004) 3184-3190.

[27] S. Li, Y. Chen, X. He, X. Mao, Y. Zhou, J. Xu, Y. Yang, Modifying reduced graphene oxide by conducting polymer through a hydrothermal polymerization method and its application as energy storage electrodes, Nanoscale research letters, 14 (2019) 1-12.

[28] J. Zang, S. J. Bao, C. M. Li, H. Bian, X. Cui, Q. Bao, K. Lian, Well-aligned cone-shaped nanostructure of polypyrrole/RuO2 and its electrochemical supercapacitor, The Journal of Physical Chemistry C, 112 (2008) 14843-14847.

[29] X. Jian, J. G. Li, H. M. Yang, L. L. Cao, E. H. Zhang, Z. H. Liang, Carbon quantum dots reinforced polypyrrole nanowire via electrostatic self-assembly strategy for high-performance supercapacitors, Carbon, 114 (2017) 533-543.

[30] A. Prasath, M. Athika, E. Duraisamy, A. S. Sharma, P. Elumalai, Carbon-quantum-dot-derived nanostructured MnO2 and Its symmetrical supercapacitor performances, Chemistry Select, 3 (2018) 8713-8723.

[31] J. Li, X. Yun, Z. Hu, L. Xi, N. Li, H. Tang, Y. Zhu, Three-dimensional nitrogen and phosphorus co-doped carbon quantum dots/reduced graphene oxide composite aerogels with a hierarchical porous structure as superior electrode materials for supercapacitors, Journal of Materials Chemistry A, 7 (2019) 26311-26325.

[32] H. M. El Sharkawy, A. S. Dhmees, A. R. Tamman, S. M. El Sabagh, R. M. Aboushahba, N. K. Allam, N-doped carbon quantum dots boost the electrochemical supercapacitive performance and cyclic stability of MoS2, Journal of Energy Storage, 27 (2020) 101078.

[33] Y. Wang, Y. Cui, D. Kong, X. Wang, B. Li, T. Cai, W. Xing, Stimulation of surface terminating group by carbon quantum dots for improving pseudocapacitance of Ti3C2Tx MXene based electrode, Carbon, 180 (2021) 118-126.

[34] E. Dhandapani, P. Sengodan, N. Duraisamy, R. Ramesh, Fabrication of semi-flexible carbon quantum dots-reinforced polypyrrole (PPy/CQDs) composite electrodes by hybrid electrospray deposition for high-performance energy storage device, International Journal of Energy Research, 46 (2022) 7277-7292.

[35] P. Prabakaran, G. Arumugam, P. Ramu, M. Selvaraj, M. A. Assiri, S. L. Rokhum, R. Rajendran, Preparation and characterization of carbon quantum dots grafted Co3O4 nanocomposite for supercapacitors application, Surfaces and Interfaces, 40 (2023) 103153.

[36] A. Inayat, K. Albalawi, A. U. Rehman, A. Y. Saad, E. A. M. Saleh, M. A. Alamri, S. M. Abbas, Tunable synthesis of carbon quantum dots from the biomass of spent tea leaves as supercapacitor electrode, Materials Today Communications, 34 (2023) 105479.

List of Journal Publications and Conference Proceedings

[1]A Paper entitled 'Synthesis of water-soluble nitrogen doped carbon quantum dots-polypyrrole nanocomposite via in-situ polymerization for high performance supercapacitor application' published in ***Journal of Energy Storage*** 74 (2023) 109371.
Sapna Sharanappa, Vijaykumar S P, Suresh D S, Abdullah Ba Shbil, H Ganesha, Veeresh S, Nagaraju Y S, Devendrappa H.
https://doi.org/10.1016/j.est.2023.109371

[2] A Paper entitled 'Synthesis and characterisation of tamarind seed husk-derived carbon quantum dots incorporated polypyrrole nanosphere composite for energy storage applications' published in ***Advances in materials and processing technologies*** (2024)1-14.
Sapna Sharanappa, Suresh D S, Vijaykumar S P, H Ganesha, Abdullah Ba Shbil, Devendrappa H.
https://doi.org/10.1080/2374068X.2024.2379083

[3] A Paper entitled "Simultaneous synthesis of carbon quantum dots and porous carbon using one step hydrothermal method for supercapacitor applications" published in ***IOP Conf. Ser.: Mater. Sci. Eng.*** 1300 (2024) 012003.
Sapna Sharanappa, Vijaykumar S P, Suresh D S, Ganesha H, Abdullah Ba Shbil, Basappa M.
doi:10.1088/1757-899X/1300/1/012003

[4] A Paper entitled "One pot hydrothermal green Synthesis and characterization of tamarind seed husk derived carbon quantum dots for energy storage applications" published in ***www.pvpsiddhartha.ac.in.*** (2024) 93-96.
Sapna Sharanappa, Vijaykumar S P, Suresh D S, Ganesha H, Abdullah Ba Shbil, Devendrappa H.
ISBN: 978-93-6128-558-5

[5] A Paper entitled 'Micelles self-degraded template based 2D graphitic carbon nitride-polypyrrole nanotube composite electrode for high supercapacitor performance' published in ***Diamond and Related Materials***, *139* (2023) 110257.
Vijaykumar SP, **Sapna S**, Suresh D S, Ganesha H, Veeresh S, Nagaraju YS, Devendrappa H.
https://doi.org/10.1016/j.diamond.2023.110257

[6] A Paper entitled 'Aesthetic synthesis and comparative study of graphitic carbon nitride for energy storage applications' published in ***Advances in materials and processing technologies*** (2024)1-16.
Vijaykumar S P, **Sapna Sharanappa**, Suresh D S, H Ganesha, Abdullah Ba Shbil, Devendrappa H.
https://doi.org/10.1080/2374068X.2024.2379084

[7] A Paper entitled "Tailored Synthesis of CN-PPy Composite for Enhanced Electrochemical Functionality" published in ***IOP Conf. Ser.: Mater. Sci. Eng.*** 1300 (2024) 012009.
Vijaykumar S P, **Sapna S**, Suresh D S, Ganesha H, Abdullah Ba Shbil.
doi:10.1088/1757-899X/1300/1/012009

[8] A Paper entitled "Novel approach towards optically active and hexagonal plate morphology of Zinc doped Perylene Tetra Carboxylic Di Anhydride composite for high photovoltaic and flexible supercapacitor performances" in ***Journal of Power Sources*** 593 (2024) 233967.
Suresh D S, Vijaykumar S P, **Sapna Sharanappa**, Abdullah Ba Shbil, H Ganesha, Veeresh S, Nagaraju Y S, Devendrappa H.
https://doi.org/10.1016/j.jpowsour.2023.233967

[9] A Paper entitled "Enhancement of crystallinity with porosity material through solvent and thermal treated eggshell waste for high-performance supercapacitor applications" published in ***Journal of Material Science: Materials in electronics*** 35, 330 (2024).
Suresh D S, Abdullah Ba Shbil, **Sapna Sharanappa**, S P Vijaykumar, H Ganesha, S Veeresh, Y S Nagaraju, H Devendrappa.
https://doi.org/10.1007/s10854-024-12021-9

[10] A Paper entitled "Synthesis, characterization of cadmium sulfide doped polymer P3HT for energy storage applications" published in ***AIP Conf. Proc.12 January 2024***; 2995(1): 020181.
Suresh D S, S Veeresh, H Ganesh, Y S Nagaraju, S P Vijaykumar, **Sapna Sharanappa**, H Devendrappa.
https://doi.org/10.1063/5.0178459

[11] A Paper entitled "Optical Properties of Lawsone dye doped with Zinc Oxide for the Fabrication of Dye Sensitized Solar Cell" published in ***IOP Conf. Ser.: Mater. Sci. Eng.*** 1300 (2024) 012002.
Suresh D S, Abdullah Ba Shbil, S P Vijaykumar, **Sapna Sharanappa**, H Ganesha.
doi:10.1088/1757-899X/1300/1/012002

[12] A Paper entitled "Polymer incorporated with graphene oxide composite for high electrochemical performance" published in ***Materials Today: Proceedings*** (2023),
Ganesha H, Veeresh S, Nagaraju YS, Suresh D Vijaykumar SP, **Sapna,** Devendrappa H.
https://doi.org/10.1016/j.matpr.2023.04.35

[13] A Paper entitled "Nilgiri tree peels-derived activated porous carbon for high performance supercapacitor applications" published in ***IOP Conf. Ser.: Mater. Sci. Eng.*** 1300 (2024) 012010.
Abdullah Ba shbil, Nagaraju Y S, Ganesha H, Veeresh S, Suresh D S, Vijaykumar S P, **Sapna Sharanappa**.
doi:10.1088/1757-899X/1300/1/012010

[14] A paper "Optical Study on Co-Sensitization of Betanin Dye with Cadmium Sulfide to Fabricate Dye Sensitized Solar Cell" published in ***journal of environmental and nanotechnology*** (2024),
D. S. Suresh, **Sapna Sharanappa**, S. P. Vijaykumar, Abdullah Ba Shbil, H. Ganesha and H. Devendrappa.
https://doi.org/10.13074/jent.2024.09.242671

[15] A Paper entitled "Synthesis and characterization of graphitic carbon nitride material used for comparative study towards electrochemical applications" published in ***AIP Conf. Proc*** 3198 (2025).
Vijaykumar Pujar Siddapp, **Sapna Sharanapp,** Suresh DS, Ganesha Honnu, Abdullah Ba Shbil, Devendrappa Hundekal.
https://doi.org/10.1063/5.0248282

[16] A Paper entitled "Hydrothermal synthesis of Rose Bengal dye particle deposition on layered reduced graphene oxide composite for photo assisted supercapacitor applications" published in ***Electrochimica Acta*** 511 (2025) 145380
Suresh D S, **Sapna Sharanappa**, Vijaykumar S P, Abdullah Ba Shbil, Ganesha, Devendrappa H.
https://doi.org/10.1016/j.electacta.2024.145380

[17] A Paper entitled "Sustainable Approach to Fabricate High-Performance Symmetry Supercapacitor Electrodes from Natural Coconut-Shell-Derived Porous Activated Carbon with Nickel Oxide Nanocomposites" published in ***ACS Omega*** 10 (2025) 11077-11090
Abdullah Ba shbil, Nagaraju Yennappa Siddappa, Suresh Daddi Suraiah, Ganesha Honnu, Vijaykumar Siddappa Pujar, **Sapna Sharanappa**, Devendrappa Hundekal.
https://doi/full/10.1021/acsomega.4c09778

[18] A Paper entitled "Nilgiri tree peels-derived activated porous carbon for high performance supercapacitor applications" published in ***IOP Conf. Ser.: Mater. Sci. Eng.*** 1300 (2024) 012010.
Abdullah Ba shbil, Nagaraju Y S, Ganesha H, Veeresh S, Suresh D S, Vijaykumar S P, **Sapna Sharanappa**.
doi:10.1088/1757-899X/1300/1/012010

International Conferences Attended and Papers Presented

[1] Participated and presented a paper entitled "*Nitrogen- doped Carbon Quantum dots-Polypyrrole composite electrode for high energy storage application"* in international e-Conference on Nanomaterials and Nanoengineering APA NANOFORUM-2022. **Sapna Sharanappa**, Vijaykumar S P, Suresh D S, Abdullah Ba Shbil, H Ganesha, Veeresh S, Nagaraju Y S, Devendrappa H.

[2] Organizing Committee member and presented a paper entitled as *"Simultaneous synthesis of carbon quantum dots and porous carbon using one step hydrothermal method for supercapacitor applications"* in the International Conference on Physics of materials and *Nanotechnology* (ICPN-2023) organized by Department of Physics, Mangalore University *held* from 21st - 23rd September, 2023.
Sapna Sharanappa, Vijaykumar S P, Suresh D S, Ganesha H, Abdullah Ba Shbil, Basappa M, Devendrappa H.

[3] Participated and presented a paper entitled *One pot hydrothermal green Synthesis and characterization of tamarind seed husk derived carbon quantum dots for energy storage applications* in international conference on emerging advances and applications in green energy (ICEAAGE-2024) organized by Department of Electrical & Electronic Engineering Prasad V. Potluri Siddhartha Institute of Technology, Kanuru, Vijayawada, Andhra Pradesh, India. 29th February 2024.
Sapna Sharanappa, Vijaykumar S P, Suresh D S, Ganesha H, Abdullah Ba Shbil, Devendrappa H.

[4] Participated and presented a paper entitled *Synthesis and characterization of tamarind seed husk derived carbon quantum dots incorporated polypyrrole nanosphere composite for energy storage applications* in 16th international conference on Materials Processing and Characterization (ICMPC-2024) organized by the Mechanical Engineering Department, Institute of Technology, Nirma University, Ahmedabad, India, from June 27 to 29, 2024.
Sapna Sharanappa, Suresh D S, Vijaykumar S P, H Ganesha, Abdullah Ba Shbil, Devendrappa H.

[5] Participated and presented a paper entitled *A facile single-pot hydrothermal synthesis and characterization of MnO_2 nanostructures for supercapacitor applications* in INTERNATIONAL CONFERENCE ON Composite Materials for Environment Protection & Remediation (ICCMEPR-2024) organized by the Gram Bharti College, Ramgarh, Kaimur, Bihar, India, from July 2 to 2, 2024.
Sapna Sharanappa, Suresh D S, Vijaykumar S P, H Abdullah Ba Shbil, Devendrappa H.

Webinars & Workshops Attended

SL. No	Organization	Period		Details of Training / Project undertaken
		From	To	
1	Center for Research and Innovations School of Natural Sciences Adichunchanagiri University, Mandya.	24th December 2021	24th December 2021	One Day International webinar on "**Two Dimensional Nanostructures for Energy Conversion and Storage Applications** "
2	Department of Education, Mangalore University, Konaje	18th February 2022	23rd February 2022	Six days workshop on "**Research Publication & Ethics**"
3	CENSE, Indian Institute of Science, Bangalore.	20th June 2022	22nd June 2022	Virtual "**INUP Basic Training Programme**"
4	department of physics, Mahalaxmi ammanni college for woman autonomous, Malleswaram Bangalore	7th December 2022	22nd December 2022	"**Refreshers course in experimental physics**"
5	Computer Centre, Mangalore University	18th January 2023	19th January 2023	"**Two Days Workshop on Latex Programming"**
6	Department of Library and information science and Mangalore University library	24th May 2024	24th May 2024	One-day Workshop on "**Wiki source for knowledge sharing**"
7	Chakreswar saikia centra library, Assam	9th June 2024	9th June 2024	One-day lecture program on "**AI based tools for literature search and systematic review**"
8	Mangalore University	20th June 2024	20th June 2024	One Day Workshop on "**Open Access Publishing**"

Dr. Devendrappa H
(Research Guide)

Sapna Sharanappa
(Research Scholar)